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ORNAMENT

Ontario Road Noise Analysis Method for Environment and Transportation

Technical Document

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The road traffic noise prediction method (ORNAMENT) is the outcome of discussions of an Advisory Committee on Road Traffic Noise, established by this Ministry and chaired by Mr. P. Joseph.

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ABSTRACT

This document presents the background and description of a procedure for the prediction of road traffic noise that has been adopted by the Ontario Ministry of Transportation and the Ministry of the Environment.

ORNAMENT has been prepared by a group of technical experts representing various agencies as well as interests.

The Ministry of the Environment requires the use of this method to assess the noise impact from existing roadways on planned residential land uses, to assess the noise impact of roadway projects, and to establish the ambient noise level criterion for the purposes of approval of new noise sources and for complaint investigation.

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1. Introduction

The impact of road traffic noise is an important factor to be considered when planning sensitive land uses. This document presents the background and description of the Ministry of the Environment's procedure for the prediction of road traffic noise based on road traffic parameters, receiver description and topographical features. The Ministry requires the use of this method to assess the noise impact from existing roadways on planned residential land uses, to assess the noise impact of roadway projects, and to establish the ambient noise level criterion for the purposes of approval of new noise sources and for complaint investigation.

Based on a model developed by the U.S. Federal Highway Administration [1], ORNAMENT was prepared by the Technical Sub-committee of an Advisory Committee on Road Traffic Noise, established by this Ministry in 1988. The sub-committee's members were: H. Gidamy (chairman), C.T. Blaney, J.E. Coulter, M. DeLint, L.G. Kende, A.D. Lightstone, J.D. Quirt, and V. Schroter.

As in the FHWA model [1], the general concept of the method is to evaluate a reference sound level and adjust it by a series of adjustments accounting for the gradient of the roadway, the pavement surface, the distance between the road and the receiver, the topography and any shielding obstructing the sound path.

The validity of the prediction method is for source-to-receiver distances from 15 m to about 500 m; however, in the range from 200 m to 500 m, the prediction accuracy decreases. This method is not recommended for distances greater than 500 m. The prediction accuracy also decreases in cases of highly irregular

topography and the method does not apply to traffic volumes less than 40 vehicles per hour and to speeds less than 50 km/h.

2. Assessment of Noise Impact

ORNAMENT is designed for Land Use Planning as well as for Abatement or Approval of new noise sources. In the former case, the prediction should be based on long term, statistically averaged road traffic information such as the SADT or AADT. In the latter type of assessment, the prediction should be based on hourly traffic volume information; the resultant one-hour equivalent sound level can subsequently be used to define the sound level limit for the impact assessment of new or existing noise sources. This section presents an introduction and a brief description of the principles of the two types of assessment.

Details of the assessment are described in the "Environmental Noise Assessment in Land Use Planning" [2], "Introductory Environmental Noise Course Manual" [3], "Certificate Environmental Noise Course Manual" [4], and "Model Municipal Noise Control By-Law" [5], published by the Ontario Ministry of the Environment.

2.1 Land Use Planning

In the context of impact assessment of road traffic noise on planned land uses such as residential subdivisions, the descriptors are the 24-hour equivalent sound level for freeways, and the 16-hour day-time and the 8-hour night-time equivalent sound level for other roads. As this prediction method determines the one-hour equivalent sound level, conversion to the longer term descriptors is necessary. The conversion from the hourly equivalent sound level to the longer term level is a function of the day-night traffic volume split: 90% - 10%, 85% - 15% and 67% - 33% are the recommended distributions for regional

roads, provincial roads and freeways respectively, see Appendix D for details.

Traffic volumes may be obtained from the following sources:

(a) Annual MTO Reports, "Provincial Highways, Traffic Volumes" published by the Highway Program Planning Office, and the "Commercial Vehicle Travel Data" published by the Transportation Demand Research Office.

(b) Traffic department of the local municipality.

In order to comply with the MOE guidelines, the noise level must be assessed in an Outdoor Living Area, such as a rear yard or a patio, and in Indoor Living Areas, such as bedrooms and living rooms. To accomplish this, the road traffic noise impact is evaluated at a minimum of two outdoor receiver locations, typically defined as follows:

- 3 m from the building facade and 1.5 m above ground, for the purposes of evaluating the sound level in the Outdoor Living Area;
- in the plane of a bedroom window, usually 4.5 m above ground at 2nd storey, for the purposes of evaluating the indoor sound level in bedrooms.

The prediction at both outdoor receiver locations yields the free-field equivalent sound level; the first location describes the actual noise impact in the Outdoor Living Area.

For the purposes of assessing the noise level in the indoor areas and, consequently, the air-conditioning and acoustical insulation requirements, the calculated free-field sound level at the facade has to be adjusted for source/receiver geometry to account for differing orientations of the road and the receiver.

Corrections to the calculated sound level for sound reflection from building facades are not generally required as the noise criteria also represent free-field sound levels.

Where the noise impact exceeds the applicable criteria, mitigation measures such as noise barriers, special building components and/or central air conditioning may be necessary. For the purposes of assessing the noise impact, an obstacle may only be considered as a "noise barrier" when the obstacle breaks the line of sight between the source and the receiver. Details of the assessment are contained in [2] and [5].

2.2 Abatement and Approval

The prediction method described in this document yields the one-hour equivalent sound level at a point of reception, i.e receiver position, which can be used to define the ambient sound level for the purposes of complaint investigation and approval of new noise sources.

In order to comply with the MOE guidelines, the noise level must be assessed at a point of reception which is defined as "any point on the premises of a person where sound or vibration originating from other than those premises is received". Details of the assessment are contained in [3], [4] and [5].

3. Description

3.1 Concept of Prediction Method

The prediction method is based on an assumption that, in acoustical terms, a roadway may be represented by a series of straight line sections (segments). For each road section vehicles are classified into one of three acoustic source groups:

automobiles, medium trucks and heavy trucks. The model is based on determination of the reference sound level which is a function of the reference energy mean emission levels for these three categories of vehicles and the average speed of traffic flow.

The major features of the model are its modular structure and a refined characterization of vehicle categories into <u>three acoustic source groups</u> (used by the original FHWA model). These features permit detailed analysis of the effects of various parameters.

The following three vehicle categories are defined:

(1) <u>Automobiles</u>
All vehicles having two axles and four wheels designed primarily for the transportation of nine or fewer passengers or the transportation of cargo (e.g. vans and light trucks). Generally, the gross vehicle weight is less than 4,500 kg.

(2) <u>Medium trucks</u>
All vehicles having two axles and six wheels designed for the transportation of cargo. Generally, the gross vehicle weight is greater than 4,500 kg but less than 12,000 kg. City buses are also included in this category.

(3) <u>Heavy trucks</u>
All vehicles having three or more axles and designed for the transportation of cargo. Generally, the gross vehicle weight is greater than 12,000 kg. Intercity buses are also included in this category.

The model uses the following prediction variables:

Hourly traffic volumes (each vehicle class);
Posted speed of traffic flow;

Separation distances;
Angles subtended at the receiver by road segments;
Ground absorption coefficients;
Road gradients;
Pavement surface types;
Shielding due to barriers (natural or man made) rows of houses and dense woods.

3.2 Method of Prediction

3.2.1 Identification of Road Segments

(a) A segment of a roadway should preferably be as long as possible providing the following variables are approximately constant:

- road alignment
- road gradient (if Heavy Trucks are present)
- type of pavement surface
- traffic flow conditions: total traffic volume, traffic composition, speed limit
- sound attenuation mechanisms: ground surface, shielding

(b) A roadway segment may be assumed to be infinite, i.e. extend from -90 to 90 degrees, providing that the roadway extends at least 6 times the perpendicular distance from the receiver to the roadway centre, in each direction. Two segments, each extending from -90 to 90 degrees would represent two infinite roadways.

(c) A roadway having more than 4 lanes must be divided into one or more sets of lanes for each direction of traffic flow. A maximum number of four lanes should be included in one set. Each set of lanes would then be represented by a series of straight line segments along its centre.

For example, in the presence of a finite noise barrier, the configuration would be represented by three segments: two on either side of the barrier and one for the barrier itself. The segment angles would be given by the angles subtended at the receiver by the barrier.

Table 10 provides the definitions of the segment angles with some examples of various configurations.

3.2.2 Reference Sound Level and Adjustments

The reference sound level is determined from the road traffic parameters and the mean emission sound levels. Adjustments to the reference sound level account for the effect of:

Road gradient
Traffic volume
Separation distance
Finite road sections
Pavement surface type
Shielding

The values of the reference sound levels and the adjustments are given in the attached Tables 3 to 6. The Percentage of Trucks (Medium + Heavy), used in the Tables, is the percentage of all trucks out the total vehicular volume. The Percentage of Medium Trucks in the Tables is the percentage of Medium Trucks out of the total Percentage of Trucks (Medium + Heavy).

It should be noted that, in case of a road gradient, the volume of Heavy Trucks must be appropriately adjusted by the Road Gradient Adjustment before it can be used to determine other percentages. Subsequent calculations, except that for the effective source height which uses the actual, unadjusted Heavy Truck percentage, also use the adjusted volume. It should be

further noted that this adjustment is only applied to the Heavy Trucks travelling in the up-grade direction.

3.2.3 Multiple Roads or Road Segments

The one-hour equivalent sound level, L_{eq}, due to traffic noise from the entire roadway is determined by combining the sound level contributions from each road segment. Similarly, the equivalent sound level due to traffic on multiple roads is calculated by combining the sound levels resulting from each individual roadway. The sound levels are combined using a logarithmic, decibel addition.

4. Basic Theory

The prediction method assumes that for a line of equally spaced vehicles, travelling at the same speed S, the equivalent sound level L_{eq} at a distance D (under the assumption of a reflective ground surface) is given by:

$$L_{eq} = 10 \log \left\{ \frac{< p_{ref}^2 >}{< p_o^2 >} \frac{N}{T} \int_{t_1}^{t_2} \left(\frac{D_{ref}}{R} \right)^2 dt \right\} \ldots (1)$$

where $< p_{ref}^2 >$ is the sound pressure at a reference distance D_{ref}

$< p_o^2 >$ $= 2 \; . \; 10^{-5}$ Pa

N is the number of vehicles within the time period T

T $= t_2 - t_1$

and R $= (D^2 + S^2t^2)^{½}$

where D is the actual distance from the road to the observation point

For a non-reflective, absorptive ground surface, the method assumes that the effect of ground on sound propagation from a single vehicle (point source) can be expressed as:

$$< p^2 >_{observed} = < p^2 >_{\substack{geometric \\ spreading}} \cdot \left\{ \substack{Excess \\ Ground \\ Attenuation \\ Factor} \right\} \qquad \ldots(2)$$

$$\text{or} \quad L_{observed} = 10 \log \left\{ \frac{< p_{ref}^2 >}{< p_o^2 >} \frac{D_{ref}^2}{D^2} e \right\}$$

where e is a factor describing the effect of ground surface on sound propagation and the distances D_{ref} and D are measured along the line connecting the point source and the receiver.

Similarly to expression (1), the sound level produced by a line of equally spaced point sources (under the assumption of an absorbent ground surface) is given by:

$$L_{eq} = 10 \log \left\{ \frac{<p_{ref}^2 >}{< p_o^2 >} \frac{N}{T} \int_{t_1}^{t_2} \left(\frac{D_{ref}}{R} \right)^2 e \, dt \right\} \qquad \ldots(3)$$

The method further assumes that the excess ground attenuation can be expressed as:

$$e\ (\varnothing) = \left(\frac{D_{ref}}{R} \right)^{\alpha} = \left(\frac{D_{ref}}{D} \right)^{\alpha} \left(\frac{1}{1 + \frac{S^2 t^2}{D^2}} \right)^{\alpha/2} \qquad \ldots(4)$$

where α is the ground absorption coefficient.

Using the conversion $St = D \tan \varnothing$ and, thus, changing the integration limits from time limits, t_1 and t_2, to angular (spatial) limits, $\varnothing_1$ and $\varnothing_2$, and integrating, the expression for the equivalent sound level produced by a finite segment of road

traffic in the presence of acoustically absorbent ground surface becomes:

$$L_{eq} = 10 \log\left(\frac{\langle p_{ref}^2 \rangle}{\langle p_o^2 \rangle}\right) + 10 \log\left(\frac{N \pi D_{ref}}{T S}\right) + 10 \log\left(\frac{D_{ref}}{D}\right)^{1+\alpha}$$

$$+ 10 \log \left\{\frac{1}{\pi}\int_{\phi_1}^{\phi_2} \cos^{\alpha} \phi \, d\phi \right\} \qquad \ldots(5)$$

For a single vehicle class and a time period T of one hour, the one-hour equivalent sound level is:

$$L_{eq} = L_o + 10 \log V + 10 \log D_{ref} + 10(1+\alpha)\log\left(\frac{D_{ref}}{D}\right) \qquad \ldots (6)$$

$$+ 10 \log \left\{\frac{1}{\pi}\int_{\phi_1}^{\phi_2} \cos^{\alpha} \phi \, d\phi \right\} - 10 \log S - 25$$

where L_o is the reference energy mean emission sound level
and V is the hourly volume.

Finally, for three classes of vehicles, automobiles, medium trucks and heavy trucks, all travelling along a straight, level road at same speed S, the one-hour equivalent sound level becomes

$$L_{eq} = 10 \log V_{ref} + 10 \log D_{ref} - 10 \log S - 25$$

$$+ 10 \log\{ P_A \, 10^{(L_o)_A/10} + P_{MT} \, 10^{(L_o)_{MT}/10} + P_{HT} \, 10^{(L_o)_{HT}/10} \}$$

$$+ 10(1+\alpha)\log\left(\frac{D_{ref}}{D}\right) + 10 \log\left(\frac{V}{V_{ref}}\right)$$

$$+ 10 \log \left\{\frac{1}{\pi}\int_{\phi_1}^{\phi_2} \cos^{\alpha} \phi \, d\phi \right\} \qquad \ldots(7)$$

where $(L_o)_A$, $(L_o)_{MT}$ and $(L_o)_{HT}$ are the reference energy mean emission sound levels of automobiles, medium trucks and heavy trucks.

and V_{ref} is a reference traffic volume.

The above expression illustrates the modular nature of the model, as the individual terms can be assigned to specific modules and evaluated separately; the terms are interpreted as follows:

$$10 \log V_{ref} + 10 \log D_{ref} - 10 \log S - 25$$

... Reference Sound Level

$$+ 10 \log\{ P_A \, 10^{(L_o)_A/10} + P_{MT} \, 10^{(L_o)_{MT}/10} + P_{HT} \, 10^{(L_o)_{HT}/10} \}$$

$$10(1 + \alpha)\log\left(\frac{D_{ref}}{D} \right)$$

... Distance Adjustment

$$10 \log\left(\frac{V}{V_{ref}} \right)$$

... Volume Adjustment

$$10 \log \left\{ \frac{1}{\pi} \int_{\varnothing_1}^{\varnothing_2} \cos^{\alpha} \varnothing \, d\varnothing \right\}$$

... Finite Segment Adjust

The following sections build on this fundamental characteristic of the model and describe each of the modules separately.

5. Modular Formulation

The modular nature of the prediction method was established in expression (7). Extending the application of this expression to situations which involve various shielding mechanisms, the one-hour equivalent sound level, L_{eq}, at a point of reception

generated by vehicles travelling on a section (segment) of a roadway may be expressed as:

$$L_{eq} = L_{ref} + A_v + A_d + A_f + A_p + A_s \qquad \ldots (8)$$

where

L_{ref}	is the	Reference sound level;
A_v	is the	Volume adjustment;
A_d	is the	Distance adjustment;
A_f	is the	Finite segment adjustment;
A_p	is the	Pavement surface adjustment;
A_s	= A_b or A_h or A_w	Shielding adjustment.

where A_b is the barrier attenuation adjustment;
A_h is the adjustment for rows of houses;
A_w is the adjustment for dense woods.

The road segment was defined in Section 3.2; in summary, it is a section of the roadway with the following properties:

(i) the width must not be more than 4 road lanes;

(ii) parameters defining the L_{eq} must be the same within the segment; these include road alignment, road gradient, pavement surface, ground surface and shielding.

The total one-hour equivalent sound level, resulting from several road segments, is given by a logarithmic addition of contribution from the individual segments:

$$L_{eq} = 10 \log[\, 10^{L_{eq1}/10} + 10^{L_{eq2}/10} + 10^{L_{eq3}/10} + \ldots] \qquad \ldots (9)$$

where L_{eq1}, L_{eq2}, and L_{eq3} are the sound levels produced by each roadway section, calculated using expression 8.

5.1 Reference Sound Levels

The reference sound level is the sound level produced by a reference traffic volume at a reference distance from the road:

$$L_{ref} = 10 \log \sum_{i=1}^{3} \{ K_g P_i 10^{(L_o)_i/10} \} + 10 \log V_{ref} - 10 \log S + 10 \log D_{ref} - 25 \qquad \ldots (10)$$

where L_{ref} is the reference hourly sound level;

$(L_o)_i$ the reference energy mean emission level of i^{th} vehicle class;

P_i the percentage of i^{th} vehicle class, expressed as fraction of the total volume;

K_g the road gradient adjustment factor for heavy trucks, see Table 1;

$K_g = 1$, automobiles and medium trucks;

$= 1$, elevation change < 6m & grade < 2%;

S the posted speed limit in km/h.

The reference energy mean emission levels of the three vehicle categories, automobiles (A), medium trucks (MT), and heavy trucks (HT), are given by:

$$\begin{aligned}(L_o)_A &= 38.1 \log(S) - 2.4 \\ (L_o)_{MT} &= 33.9 \log(S) + 16.4 \qquad \ldots (11) \\ (L_o)_{HT} &= 24.6 \log(S) + 38.5\end{aligned}$$

The reference sound levels are given in Tables 3,4,5 and 6; the reference energy mean emission levels are plotted against the posted speed limit S in Figure 1.

5.2 Road Gradient Adjustment

This adjustment is applied to heavy trucks travelling in the upgrade direction when road gradient is more than 2 % and the change in elevation is more than 6 m. The adjustment is in the form of a multiplication factor K_g applied to number of trucks travelling up the grade. Values of this factor are tabulated in Table 1.

5.3 Traffic Volume Adjustment

The adjustment to the traffic volume V is given by

$$A_v \quad = \quad 10 \log(V/V_{ref}) \quad = \quad 10 \log (V/40) \qquad \ldots(12)$$

where V_{ref} is the reference traffic volume, V_{ref} = 40 vph.

Figure 2 and Table 2 present the volume adjustment.

5.4 Pavement Surface Adjustment

This adjustment is applicable when the posted speed limit is equal or greater than 80 km/h. The values of the adjustment are given in Table 12.

5.5 Distance Adjustment

The distance adjustment, which accounts both for the geometric spreading as well as the effect of ground surface, is given by the following expression:

$$A_d \quad = \quad 10 \ (1 + \alpha) \ \log(D_{ref}/D) \qquad \ldots (13)$$

where

1. Reflective Surfaces (hard ground)

   $\alpha = 0$

2. Absorptive Surfaces (soft ground)

   $\alpha = 0.66 \,, \qquad h_{eff} \leq 3 \text{ m}$

   $\alpha = 0.75 \left(1 - \frac{h_{eff}}{25} \right) \,, \qquad 3 < h_{eff} \leq 25 \text{ m}$

   $\alpha = 0 \,, \qquad h_{eff} > 25 \text{ m}$

where α is the ground absorption coefficient and
h_{eff} is the total effective height.

Distance adjustment values are shown in Table 7 and Figure 3.

5.5.1 Reflective Surfaces

Water surfaces and hard ground surfaces (e.g. all pavements, and hard packed gravel, earth, etc.) are considered to be sound reflective. If more than half of the ground surface between the centre line of the traffic lanes under consideration and the point of reception is sound reflective, the ground absorption coefficient, α, is assumed to be zero.

5.5.2 Absorptive Surfaces

Soft ground surfaces such as ploughed fields, or ground covered with grass, shrubs, or other forms of vegetation are considered to be sound absorptive. If more than half of the ground surface between the centre line of the traffic lanes under consideration and the point of reception is sound absorptive, the ground absorption coefficient is assumed to be given by the expression for absorptive ground, varying between 0 and 0.66.

5.5.3 Total Effective Height

The total effective height (h_{eff}) is defined as a function of the receiver height (r), effective source height (s), barrier height (h), height of woods (w), and the change of ground elevation (e). For a flat ground of any grade, for example, the total effective height is given by

$$h_{eff} = s + r$$

Definitions of the total effective height are given in Figure 4. The actual topographical situations should, where possible, be modelled by one of the cases shown in Figure 4. Configurations which cannot be modelled by one of the cases have to be assessed by other means.

Application of Figure 4 is restricted to topographies for which the horizontal distances are much greater than the vertical distances. In cases where the vertical distance, such as the elevation, is of the same order of magnitude as any of the horizontal distances, other means of assessment are necessary.

5.5.4 Receiver and Source Heights

The height of the receiver above ground is not specifically defined in the sound level prediction method. However, for the purposes of assessing the noise impact on single family dwellings and townhouse units, the following receiver heights are used:

1.5 m, defining the outdoor living area;
4.5 m, defining a 2nd storey window.

The source height is represented by an effective height of the combined traffic sound source above the road surface. The following expression defines the effective source height:

$$
\begin{aligned}
s &= 0.5 \text{ m}, && P_{HT} < 0.01 \\
&= \sqrt[4]{100\ P_{HT}}, && 0.01 \le P_{HT} \le 0.30 \\
&= 2.4 \text{ m}, && P_{HT} > 0.30
\end{aligned}
$$

where P_{HT} is the percentage of heavy trucks, unadjusted by the gradient factor, expressed as a fraction of the total volume.

Table 8 presents the effective source height in a tabular form.

5.6 Finite Segment Adjustment

It is often necessary to divide a roadway into segments in order to account for the different road traffic parameters such as, the change in road alignment (horizontal/vertical), traffic flow conditions, etc. To account for the reduction in acoustic energy emitted from a section of roadway due to its finite length, an adjustment must be made to the reference sound level. The adjustment is dependent, not only on the angle subtended at the receiver by the road segment, but also on the type of ground surface within the area of the subtended angle.

The adjustment for a finite segment, i.e. finite length of the road, is given by the following expression:

$$A_f = 10 \log \left\{ \frac{1}{\pi} \int_{\emptyset_1}^{\emptyset_2} \cos^{\alpha} \emptyset \; d\emptyset \right\} \qquad \ldots(14)$$

The angles $\emptyset_1$ and $\emptyset_2$, expressed in radians, define the extent of the road segment at the receiver location, see Table 10. The expression applies universally to all surfaces; however, in case of a reflective surface, the expression simplifies to

$$A_f = 10 \log \left\{ \frac{\emptyset_2 - \emptyset_1}{\pi} \right\}, \text{ Reflective surface} \qquad \ldots(15)$$

Figure 5 and Table 9 present the adjustment for reflective ground surfaces. Figures 6.1 through to 6.4, and Tables 11.1 through to 11.4 present the adjustment for absorptive ground surfaces.

5.7 Shielding Adjustment

The shielding adjustment is found from the shielding effect provided by three potential obstacles:

- dense woods
- barriers
- rows of houses

In case of a combination of two or three obstacles, such as woods and houses, or barrier and houses, the sound level L_{eq} is evaluated using the individual shielding adjustments in the absence of the other and the value of A_b, A_h or A_w which, in combination with the distance and finite segment adjustments, A_d and A_f, results in the lowest sound level is used:

$$A_s = A_b \text{ or } A_h \text{ or } A_w, \quad \text{whichever produces the lowest } L_{eq} \text{ when combined with } A_d + A_f.$$

5.7.1 Adjustment for Dense Woods

An adjustment may be made to account for the presence of trees providing they are very dense, i.e no visual path between the road and the receiver, and the height of the trees is a minimum of 5 m above the line of sight. In addition, any assessment must discuss and justify the use of the adjustment, and confirm that the presence of the trees will be maintained. Table 13 presents the adjustment versus the depth of the woods.

When this adjustment is used in combination with the distance adjustment for absorptive ground surface, the effective height of the source and receiver must be increased by twice the minimum tree height (w), i.e. by 10 m, see Figure 4.

5.7.2 Adjustment for Barriers (Barrier Attenuation)

Details of the concept and the method evaluating the barrier attenuation are given in Appendix A; the resultant expressions of the analysis are given below.

Barrier attenuation is given by the following expressions:

$$\ldots(16)$$

$$A_b = 10 \log \left\{ \frac{1}{\Theta_2 - \Theta_1} \int_{\Theta_1}^{\Theta_2} f_1(\Theta) \quad d\Theta \right\} \qquad \text{for } N_o < 0$$

$$A_b = -5 \text{ dB}, \qquad \text{for } N_o = 0$$

$$A_b = 10 \log \left\{ \frac{1}{\Theta_2 - \Theta_1} \int_{\Theta_1}^{\Theta_2} f_2(\Theta) \quad d\Theta \right\} \qquad \text{for } N_o > 0$$

where

$$f_1 (\Theta) = 1 \qquad \text{for } N_o \cos \Theta \le -0.1916$$

$$f_1 (\Theta) = \frac{\tan^2 \sqrt{2\pi \; |N_o| \; \cos \Theta}}{\sqrt{10} \;\; 2\pi \; |N_o| \; \cos \Theta} \qquad \text{for } -0.1916 < N_o \cos \Theta < 0$$

$$f_1 (\Theta) = f_2 (\Theta) = \frac{1}{\sqrt{10}} \qquad \text{for } N_o \cos \Theta = 0$$

and

$$f_2(\Theta) = \frac{\tanh^2 \sqrt{2\pi N_o \cos\Theta}}{\sqrt{10}\ \ 2\pi N_o \cos\Theta} \qquad \text{for } 0 < N_o \cos\Theta \le 5.03$$

$$f_2(\Theta) = \frac{1}{100} \qquad \text{for } N_o \cos\Theta > 5.03$$

where N_o is Fresnel Number at 500 Hz,

N_o = (2f/c) x (PLD) = 2.915 x (Path Length Difference in meters),

and Θ_1 and Θ_2 are the angles subtended by the finite barrier at the receiver. These angles generally define the road segment size and, therefore, are identical to angles $\varnothing_1$ and $\varnothing_2$.

Barrier attenuation may only be utilized in the calculation when the barrier breaks the line of sight between the source and the receiver. The adjustment for infinite barriers (infinite barrier attenuation) is presented in Table 15. In addition, approximate values of the adjustment for finite barriers are given in Appendix C, Tables C1 and C2. However, exact values of the adjustment for finite barriers have to be calculated using the above expressions. Note that the barrier must subtend a minimum of 10 degrees before it can be considered.

5.7.3 Adjustment for Rows of Houses

An adjustment to account for the presence of rows of houses between the source and the receiver is dependent on the percentage of gaps between the houses and on the source-receiver distance; Table 14 and Figure 7 give the value of the adjustment. When the road and the receiver are separated by more than one row of houses, 1.5 dB should be added for each additional row.

Appendix B provides details of the method that was used to generate the values of the adjustment.

In general, the adjustment applies to both the receiver on the ground as well as the receiver at the 2nd storey window. However, when the screening is being provided by a row of single storey houses such as bungalows, the adjustment may only be applied to the ground level receiver. Furthermore, the adjustment is only applicable in the context of a subdivision, for a receiver between rows of houses or behind the last row. The validity of the adjustment is limited to rows of houses where the houses occupy at minimum of 20 % of the row. Furthermore, the adjustment is not applicable for large row-to-receiver distances.

When this adjustment is used in combination with the distance adjustment for absorptive ground, the total effective height is given by the effective source height and receiver height.

6. References

[1] "FHWA Highway Traffic Noise Prediction Model", T.M. Barry and J.A. Reagan, U.S. Federal Highway Administration, Report FHWA-RD-77-108, December, 1978.

[2] "Environmental Noise Assessment in Land Use Planning", Ontario Ministry of the Environment, 2nd Edition. (Under preparation.)

[3] "Introductory Environmental Noise Course Manual", Ontario Ministry of the Environment, 1988.

[4] "Certificate Environmental Noise Course Manual", Ontario Ministry of the Environment, 1989.

[5] "Model Municipal Noise Control By-Law, Final Report", Ontario Ministry of the Environment, 1978.

[6] "Noise Reduction by Screens", Maekawa, E., Memorandum; Faculty of Engineering, Kobe University, 11, p. 29, 1965.

[7] "Sound Attenuation by Barriers", Kurze, U.J. and Anderson, G.S., Applied Acoustics 4, pp. 35-53, 1971.

[8] "The Calculation of Road Traffic Noise", United Kingdom Department of Environment, HMSO London (1975).

[9] "Road Traffic Noise", Department of Main Roads, N.S.W., Australia (1987).

TABLE 1

Adjustment to Percentage of Heavy Trucks on Up-Hill Grades

Road Gradient (%)	Adjustment Factor (multiplicative)
0 to less than 2	1
2 to less than 5	1.5
5 to less than 7	2
7 and more	3

TABLE 2

Adjustment to the Reference Hourly Sound Level for Traffic Volume

Use the nearest listed value when the actual value is not listed

Hourly Traffic Volume	Adjustment (Additive) (dBA)	Hourly Traffic Volume	Adjustment (Additive) (dBA)	Hourly Traffic Volume	Adjustment (Additive) (dBA)
40	0	315	9	2000	17
50	1	400	10	2500	18
63	2	500	11	3150	19
80	3	630	12	4000	20
100	4	800	13	5000	21
125	5	1000	14	6300	22
160	6	1250	15	8000	23
200	7	1600	16	10000	24
250	8				

TABLES 3 - 6:

Reference Sound Level (dBA) at 15 m and 40 vph for given % of Medium Trucks out of Total Truck %. Use the nearest listed value if actual value of speed and/or percentage is not listed.

TABLE 3: Medium Truck % = 12.5

Posted Speed (km/h)	Total Percentage of Trucks (MEDIUM + HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47.8	49.4	51.4	52.8	54.3	55.4	56.5	57.6	58.5	59.8	60.8	62.0	63.3	64.2
50	50.0	51.4	53.2	54.5	55.9	57.0	58.1	59.2	60.0	61.2	62.3	63.5	64.7	65.6
60	51.9	53.1	54.7	55.9	57.3	58.3	59.4	60.4	61.3	62.4	63.5	64.7	65.9	66.8
70	53.5	54.6	56.1	57.2	58.4	59.4	60.5	61.5	62.3	63.5	64.5	65.7	66.9	67.8
80	55.0	55.9	57.2	58.3	59.5	60.4	61.4	62.4	63.2	64.4	65.4	66.6	67.8	68.7
90	56.3	57.1	58.3	59.3	60.4	61.3	62.3	63.3	64.1	65.2	66.2	67.4	68.5	69.5
100	57.4	58.2	59.3	60.2	61.3	62.2	63.1	64.1	64.8	66.0	66.9	68.1	69.2	70.2

TABLE 4: Medium Truck % = 37.5

Posted Speed (km/h)	Total Percentage of Trucks (MEDIUM + HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47.4	48.7	50.6	51.9	53.3	54.4	55.5	56.6	57.5	58.7	59.7	60.9	62.1	63.1
50	49.7	50.8	52.5	53.7	55.0	56.1	57.1	58.2	59.0	60.2	61.3	62.5	63.7	64.6
60	51.6	52.6	54.1	55.2	56.5	57.5	58.5	59.5	60.4	61.5	62.5	63.7	64.9	65.9
70	53.3	54.2	55.5	56.6	57.8	58.7	59.7	60.7	61.5	62.6	63.7	64.8	66.0	66.9
80	54.8	55.6	56.8	57.8	58.9	59.8	60.7	61.7	62.5	63.6	64.6	65.8	67.0	67.9
90	56.1	56.8	57.9	58.8	59.9	60.8	61.7	62.6	63.4	64.5	65.5	66.6	67.8	68.7
100	57.3	57.9	59.0	59.8	60.8	61.7	62.6	63.5	64.2	65.3	66.3	67.4	68.6	69.5

TABLE 5: Medium Truck % = 62.5

Posted Speed (km/h)	Total Percentage of Trucks (MEDIUM + HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47.4	48.7	50.6	51.9	53.3	54.4	55.5	56.6	57.5	58.7	59.7	60.9	62.1	63.1
50	49.7	50.8	52.5	53.7	55.0	56.1	57.1	58.2	59.0	60.2	61.3	62.5	63.7	64.6
60	51.6	52.6	54.1	55.2	56.5	57.5	58.5	59.5	60.4	61.5	62.5	63.7	64.9	65.9
70	53.3	54.2	55.5	56.6	57.8	58.7	59.7	60.7	61.5	62.6	63.7	64.8	66.0	66.9
80	54.8	55.6	56.8	57.8	58.9	59.8	60.7	61.7	62.5	63.6	64.6	65.8	67.0	67.9
90	56.1	56.8	57.9	58.8	59.9	60.8	61.7	62.6	63.4	64.5	65.5	66.6	67.8	68.7
100	57.3	57.9	59.0	59.8	60.8	61.7	62.6	63.5	64.2	65.3	66.3	67.4	68.6	69.5

TABLE 6: Medium Truck % = 87.5

Posted Speed (km/h)	Total Percentage of Trucks (MEDIUM + HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47.4	48.7	50.6	51.9	53.3	54.4	55.5	56.6	57.5	58.7	59.7	60.9	62.1	63.1
50	49.7	50.8	52.5	53.7	55.0	56.1	57.1	58.2	59.0	60.2	61.3	62.5	63.7	64.6
60	51.6	52.6	54.1	55.2	56.5	57.5	58.5	59.5	60.4	61.5	62.5	63.7	64.9	65.9
70	53.3	54.2	55.5	56.6	57.8	58.7	59.7	60.7	61.5	62.6	63.7	64.8	66.0	66.9
80	54.8	55.6	56.8	57.8	58.9	59.8	60.7	61.7	62.5	63.6	64.6	65.8	67.0	67.9
90	56.1	56.8	57.9	58.8	59.9	60.8	61.7	62.6	63.4	64.5	65.5	66.6	67.8	68.7
100	57.3	57.9	59.0	59.8	60.8	61.7	62.6	63.5	64.2	65.3	66.3	67.4	68.6	69.5

TABLE 7

Adjustment for Distance from Source to Point of Reception

Total Effect Height (m)	Ground Absorp Coeff α	Perpendicular Distance from Source to Point of Reception (m)												
		15	20	30	40	50	60	80	100	120	150	200	250	500
		Adjustment in dBA for Non-Reflective Surfaces												
1.5	0.66	0.0	-2.1	-5.0	-7.1	-8.7	-10.0	-12.1	-13.7	-15.0	-16.6	-18.7	-20.3	-25.3
2.0	0.66	0.0	-2.1	-5.0	-7.1	-8.7	-10.0	-12.1	-13.7	-15.0	-16.6	-18.7	-20.3	-25.3
3.0	0.66	0.0	-2.1	-5.0	-7.1	-8.7	-10.0	-12.1	-13.7	-15.0	-16.6	-18.7	-20.3	-25.3
4.0	0.63	0.0	-2.0	-4.9	-6.9	-8.5	-9.8	-11.9	-13.4	-14.7	-16.3	-18.3	-19.9	-24.8
6.0	0.57	0.0	-2.0	-4.7	-6.7	-8.2	-9.5	-11.4	-12.9	-14.2	-15.7	-17.7	-19.2	-23.9
8.0	0.51	0.0	-1.9	-4.5	-6.4	-7.9	-9.1	-11.0	-12.4	-13.6	-15.1	-17.0	-18.4	-23.0
10.0	0.45	0.0	-1.8	-4.4	-6.2	-7.6	-8.7	-10.5	-11.9	-13.1	-14.5	-16.3	-17.7	-22.1
12.0	0.39	0.0	-1.7	-4.2	-5.9	-7.3	-8.4	-10.1	-11.5	-12.6	-13.9	-15.6	-17.0	-21.2
16.0	0.27	0.0	-1.6	-3.8	-5.4	-6.6	-7.6	-9.2	-10.5	-11.5	-12.7	-14.3	-15.5	-19.3
20.0	0.15	0.0	-1.4	-3.5	-4.9	-6.0	-6.9	-8.4	-9.5	-10.4	-11.5	-12.9	-14.1	-17.5
25.0 and up	0.00	0.0	-1.2	-3.0	-4.3	-5.2	-6.0	-7.3	-8.2	-9.0	-10.0	-11.2	-12.2	-15.2
		Adjustment in dBA for Reflective Surfaces												
all	0.00	0.0	-1.2	-3.0	-4.3	-5.2	-6.0	-7.3	-8.2	-9.0	-10.0	-11.2	-12.2	-15.2

TABLE 8

Effective Source Height of Road Traffic

Unadjusted Percentage of Heavy Trucks in Total Volume (%)	Effective Source Height (m)
0	0.5
1	1.0
2	1.2
3	1.3
4	1.4
5	1.5
6 to 7	1.6
8 to 9	1.7
10 to 11	1.8
12 to 14	1.9
15 to 17	2.0
18 to 21	2.1
22 to 25	2.2
26 to 30	2.3
More than 30	2.4

TABLE 9

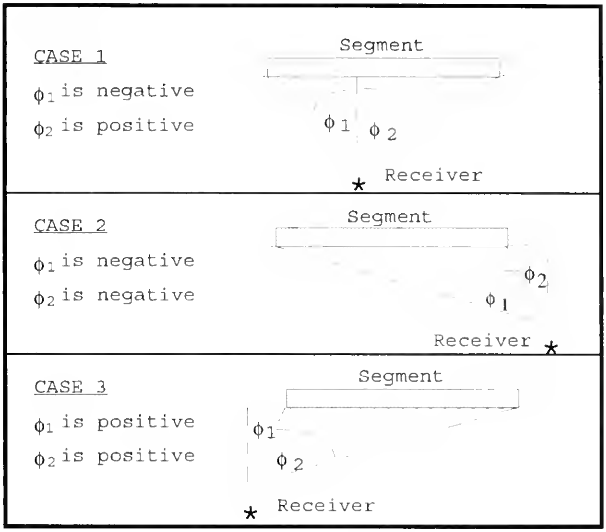
Adjustment for Finite Segment: Reflective Surface

Subtended Angle $\Phi_2 - \Phi_1$ (deg)	Adjustment (dBA)	Subtended Angle $\Phi_2 - \Phi_1$ (deg)	Adjustment (dBA)
180	0.0	50	-5.6
160	-0.5	45	-6.0
140	-1.1	40	-6.5
120	-1.8	35	-7.1
100	-2.5	30	-7.8
90	-3.0	25	-8.6
80	-3.5	20	-9.5
70	-4.1	15	-10.8
60	-4.8	10	-12.6
55	-5.1	5	-15.6

TABLE 10

Angular Relationship between Road Segments and Receiver Locations

SEGMENT, ANGLES AND RECEIVER



EXAMPLES

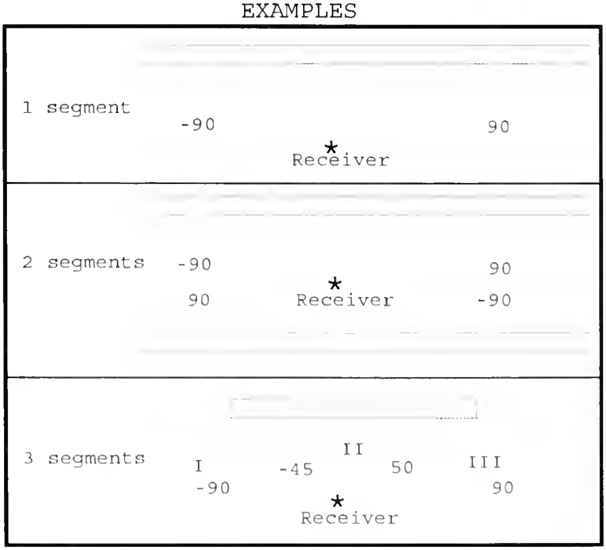


TABLE 11.1
Adjustment for Finite Segment

$\alpha = 0.1$

Segment Angles		ϕ_2																	
		-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
		Adjustment in dBA																	
	-90	-13.7	-10.4	-8.5	-7.1	-6.1	-5.2	-4.5	-3.8	-3.3	-2.8	-2.4	-2.0	-1.6	-1.3	-1.0	-0.7	-0.5	-0.3
	-80	-	-13.1	-10.0	-8.2	-6.9	-5.9	-5.0	-4.3	-3.7	-3.2	-2.7	-2.3	-1.9	-1.5	-1.2	-1	-0.7	-0.5
	-70	-	-	-12.9	-9.9	-8.0	-6.7	-5.7	-4.9	-4.2	-3.6	-3.1	-2.6	-2.2	-1.9	-1.5	-1.2	-1.0	-0.7
	-60	-	-	-	-12.8	-9.7	-7.9	-6.7	-5.7	-4.9	-4.2	-3.6	-3.1	-2.6	-2.2	-1.9	-1.5	-1.2	-1.0
	-50	-	-	-	-	-12.7	-9.7	-7.9	-6.6	-5.6	-4.8	-4.1	-3.6	-3.1	-2.6	-2.2	-1.9	-1.5	-1.3
	-40	-	-	-	-	-	-12.6	-9.6	-7.8	-6.6	-5.6	-4.8	-4.1	-3.6	-3.1	-2.6	-2.2	-1.9	-1.6
	-30	-	-	-	-	-	-	-12.6	-9.6	-7.8	-6.5	-5.6	-4.8	-4.1	-3.6	-3.1	-2.6	-2.3	-2.0
	-20	-	-	-	-	-	-	-	-12.6	-9.6	-7.8	-6.5	-5.6	-4.8	-4.1	-3.6	-3.1	-2.7	-2.4
ϕ_1	-10	-	-	-	-	-	-	-	-	-12.6	-9.5	-7.8	-6.5	-5.6	-4.8	-4.2	-3.6	-3.2	-2.8
	0	-	-	-	-	-	-	-	-	-	-12.6	-9.6	-7.8	-6.6	-5.6	-4.9	-4.2	-3.7	-3.3
	10	-	-	-	-	-	-	-	-	-	-	-12.6	-9.6	-7.8	-6.6	-5.7	4.9	-4.3	-3.8
	20	-	-	-	-	-	-	-	-	-	-	-	-12.6	-9.6	-7.9	6.7	-5.7	-5.0	-4.5
	30	-	-	-	-	-	-	-	-	-	-	-	-	-12.6	-9.7	-7.9	-6.7	5.9	-5.2
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-12.7	-9.7	-8.0	-6.9	-6.1
	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.8	-9.9	-8.2	-7.1
	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-12.9	-10.0	-8.5
	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13.1	-10.4
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13.7

TABLE 11.2
Adjustment for Finite Segment

$\alpha = 0.3$

Segment Angles		ϕ_2 -80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
		Adjustment in dBA																	
	-90	-16.0	-12.1	-9.8	-8.2	-6.9	-5.9	-5.1	-4.4	-3.8	-3.2	-2.8	-2.3	-2.0	-1.6	-1.4	-1.1	-0.9	-0.8
	-80		-14.3	-11.0	-9.0	-7.5	-6.4	-5.5	-4.7	-4.1	-3.5	-3.0	-2.5	-2.1	-1.8	-1.5	-1.3	-1.0	-0.9
	-70		-	-13.7	-10.5	-8.5	-7.2	-6.1	-5.2	-4.5	-3.9	-3.3	-2.8	-2.4	-2.1	-1.7	-1.5	-1.3	-1.1
	-60		-	-	-13.3	-10.1	-8.3	-6.9	-5.9	-5.0	-4.3	-3.7	-3.2	-2.8	-2.4	-2.0	-1.7	-1.5	-1.4
	-50		-	-	-	-13.0	-9.9	-8.1	-6.8	-5.7	-4.9	-4.2	-3.7	-3.2	-2.7	-2.4	-2.1	-1.8	-1.6
	-40		-	-	-	-	-12.8	-9.7	-7.9	-6.6	-5.7	-4.9	-4.2	-3.6	-3.2	-2.8	-2.4	-2.1	-2.0
	-30		-	-	-	-	-	-12.7	-9.6	-7.8	-6.6	-5.6	-4.8	-4.2	-3.7	-3.2	-2.8	-2.5	-2.3
	-20		-	-	-	-	-	-	-12.6	-9.6	-7.8	-6.6	-5.6	-4.9	-4.2	-3.7	-3.3	-3.0	-2.8
ϕ_1	-10		-	-	-	-	-	-	-	-12.6	-9.5	-7.8	-6.6	-5.7	-4.9	-4.3	-3.9	-3.5	-3.2
	0		-	-	-	-	-	-	-	-	-12.6	-9.6	-7.8	-6.6	-5.7	-5.0	-4.5	-4.1	-3.8
	10		-	-	-	-	-	-	-	-	-	-12.6	-9.6	-7.9	-6.8	-5.9	-5.2	-4.7	-4.4
	20		-	-	-	-	-	-	-	-	-	-	-12.7	-9.7	-8.1	-6.9	-6.1	-5.5	-5.1
	30		-	-	-	-	-	-	-	-	-	-	-	-12.8	-9.9	-8.3	-7.2	-6.4	-5.9
	40		-	-	-	-	-	-	-	-	-	-	-	-	-13.0	-10.1	-8.5	-7.5	-6.9
	50		-	-	-	-	-	-	-	-	-	-	-	-	-	-13.3	-10.5	-9.0	-8.2
	60		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13.7	-11.0	-9.8
	70		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14.3	-12.1
	80				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16.0

TABLE 11.3
Adjustment for Finite Segment

$\alpha = 0.5$

Segment Angles	ϕ_2																	
	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
	Adjustment in dBA																	
-90	-18.1	-13.6	-11.0	-9.1	-7.7	-6.6	-5.7	-4.9	-4.2	-3.6	-3.1	-2.6	-2.3	-1.9	-1.7	-1.4	-1.3	-1.2
-80	-	-15.5	-11.9	-9.7	-8.2	-6.9	-5.9	-5.1	-4.4	-3.8-	3.2	-2.8	-2.4	-2.0	-1.8	-1.5	-1.4	-1.3
-70	-	-	-14.4	-11.1	-9.0	-7.6	-6.4	-5.5	-4.7	-4.1-	3.5	-3.0	-2.6	-2.2	-1.9	-1.7	-1.5	-1.4
-60	-	-	-	-13.8	-10.5	-8.6	-7.2	-6.1	-5.2	-4.5-	3.9	-3.3	-2.9	-2.5	-2.2	-1.9	-1.8	-1.7
-50	-	-	-	-	-13.3	-10.1	-8.2	-6.9	-5.9	-5.0-	4.3	-3.7	-3.3	-2.8	-2.5	-2.2	-2.0	-1.9
-40	-	-	-	-	-	-13.0	-9.9	-8.0	-6.7	-5.7-	4.9	-4.2	-3.7	-3.3	-2.9	-2.6	-2.4	-2.3
-30	-	-	-	-	-	-	-12.8	-9.7	-7.9	-6.6-	5.6	-4.9	-4.2	-3.7	-3.3	-3.0	-2.8	-2.6
-20	-	-	-	-	-	-	-	-12.6	-9.6	-7.8-	6.6	-5.6	-4.9	-4.3	-3.9	-3.5	-3.2	-3.1
ϕ_1 -10	-	-	-	-	-	-	-	-	-12.6	-9.6-	7.8	-6.6	-5.7	-5.0	-4.5	-4.1	-3.8	-3.6
0	-	-	-	-	-	-	-	-	-	-12.6	-9.6	-7.9	-6.7	-5.9	-5.2	-4.7	-4.4	-4.2
10	-	-	-	-	-	-	-	-	-	-	-12.6	-9.7	-8.0	-6.9	-6.1	-5.5	-5.1	-4.9
20	-	-	-	-	-	-	-	-	-	-	-	-12.8	-9.9	-8.2	-7.2	-6.4	-5.9	-5.7
30	-	-	-	-	-	-	-	-	-	-	-	-	-13.0	-10.1	-8.6	-7.6	-6.9	-6.6
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-13.3	10.5	-9.0	-8.2	-7.7
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13.8	-11.1	-9.7	-9.1
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14.4	-11.9	-11.0
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-15.5	-13.6
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-18.1

TABLE 11.4
Adjustment for Finite Segment

$\alpha = 0.66$

Segment Angles ϕ	ϕ_2 -80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
	Adjustment in dBA																	
-90	-19.8	-14.8	-11.9	-9.9	-8.3	-7.1	-6.1	-5.2	-4.5	-3.8	-3.3	-2.8	-2.5	-2.1	-1.9	-1.7	-1.5	-1.5
-80	-	-16.4	-12.7	-10.3	-8.6	-7.3	-6.2	-5.4	-4.6	-4.0	-3.4	-2.9	-2.5	-2.2	-1.9	-1.7	-1.6	-1.5
-70	-	-	-15.0	-11.6	-9.4	-7.9	-6.7	-5.7	-4.9	-4.2	-3.6	-3.1	-2.7	-2.4	-2.1	-1.9	1.7	-1.7
60	-	-	-	-14.2	-10.8	-8.8	-7.4	-6.2	-5.3	-4.6	-4.0	-3.4	-3.0	-2.6	-2.3	-2.1	-1.9	-1.9
-50	-	-	-	-	13.6	-10.3	-8.4	-7.0	-5.9	-5.1	-4.4	-3.8	-3.3	-2.9	-2.6	-2.4	-2.2	-2.1
-40	-	-	-	-	-	-13.1	-10.0	-8.1	-6.8	-5.8	-4.9	-4.3	-3.8	-3.3	-3.0	-2.7	-2.5	-2.5
-30	-	-	-	-	-	-	-12.8	-9.7	-7.9	-6.6	-5.7	-4.9	-4.3	-3.8	-3.4	-3.1	-2.9	-2.8
20	-	-	-	-	-	-	-	-12.7	-9.6	-7.8	-6.6	-5.7	-4.9	-4.4	-4.0	-3.6	-3.4	-3.3
-10	-	-	-	-	-	-	-	-	-12.6	-9.6	-7.8	-6.6	-5.8	-5.1	-4.6	-4.2	-4.0	-3.8
0	-	-	-	-	-	-	-	-	-	-12.6	-9.6	-7.9	-6.8	-5.9	-5.3	-4.9	-4.6	-4.5
10	-	-	-	-	-	-	-	-	-	-	-12.7	-9.7	-8.1	-7.0	-6.2	-5.7	-5.4	-5.2
20	-	-	-	-	-	-	-	-	-	-	-	-12.8	-10.0	-8.4	-7.4	6.7	-6.2	-6.1
30	-	-	-	-	-	-	-	-	-	-	-	-	-13.1	-10.3	-8.8	-7.9	-7.3	-7.1
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-13.6	-10.8	-9.4	-8.6	-8.3
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14.2	-11.6	-10.3	-9.9
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-15.0	-12.7	-11.9
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16.4	-14.8
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.8

TABLE 12

Adjustment for Pavement Surface

Pavement Surface Type	Attenuation (dBA)
Typical asphalt (as HL-1) or concrete	0
Open-graded friction course	-2.5
Grooved concrete pavement (not used on new highways)	7

TABLE 13

Adjustment for Dense Woods

Minimum Depth of Woods between Source and Receiver (m)	Attenuation (dBA)
less than 30	0
30 to 60	-5
60 and up	-10

TABLE 14

Adjustment For Rows Of Houses

First Row of Houses					
Percentage of Row Occupied by Houses (1-p)	Distance from Source to Point of Reception (m)				
	30	60	120	240	480
	Adjustment in dBA				
20	-0.9	-0.9	-0.9	-0.8	-0.8
25	-1.2	-1.2	-1.1	-1.1	-1
30	-1.5	-1.4	-1.4	-1.3	-1.3
35	-1.8	-1.7	-1.7	-1.6	-1.5
40	-2.1	-2.0	-2.0	-1.9	-1.8
45	-2.4	-2.4	-2.3	-2.2	-2.1
50	-2.8	-2.7	-2.6	-2.5	-2.4
55	-3.2	-3.1	-3.0	-2.9	-2.7
60	-3.7	-3.6	-3.4	-3.2	-3.0
65	-4.2	-4.0	-3.9	-3.7	-3.4
70	-4.7	-4.6	-4.4	-4.1	-3.8
75	-5.4	-5.2	-5.0	-4.7	-4.3
80	-6.2	-5.9	-5.6	-5.3	-4.8
85	-7.1	-6.8	-6.4	-6.0	-5.4
90	-8.4	-7.9	-7.4	-6.8	-6.1
95	10.1	-9.4	-8.6	-7.8	-6.9
Additional Rows of Houses					
Apply adjustment of -15 dBA for each successive row					

TABLE 15

Adjustment for Infinite Barriers
(Infinite Barrier Attenuation)

PLD (m)	Fresnel Number	Attenuation (dB)
0.00	0.00	-5.0
0.02	0.06	-5.6
0.05	0.15	-6.4
0.10	0.29	-7.4
0.15	0.44	-8.2
0.20	0.58	-8.9
0.25	0.73	-9.4
0.30	0.87	-9.9
0.40	1.17	-10.7
0.50	1.46	-11.4
0.70	2.04	-12.4
1.00	2.92	-13.6

PLD is the Path Length Difference
Fresnel Number = 2.915 * PLD

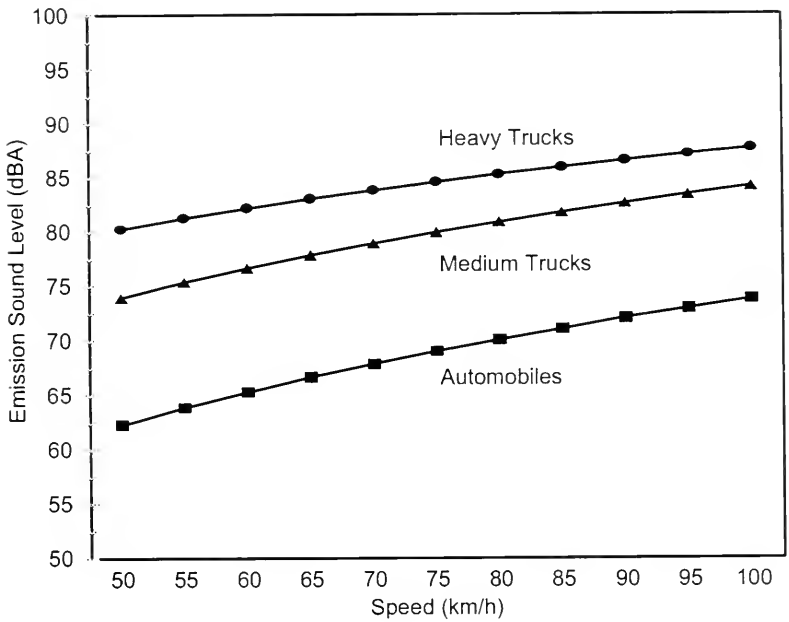


Figure 1: Reference Energy Mean Emission Sound Levels of Automobiles, Medium Trucks and Heavy Trucks

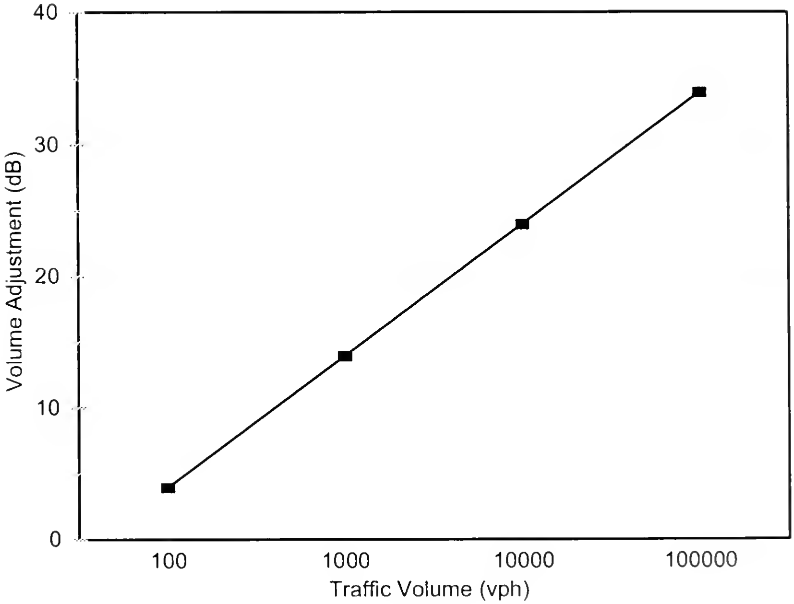


Figure 2: Volume Adjustment

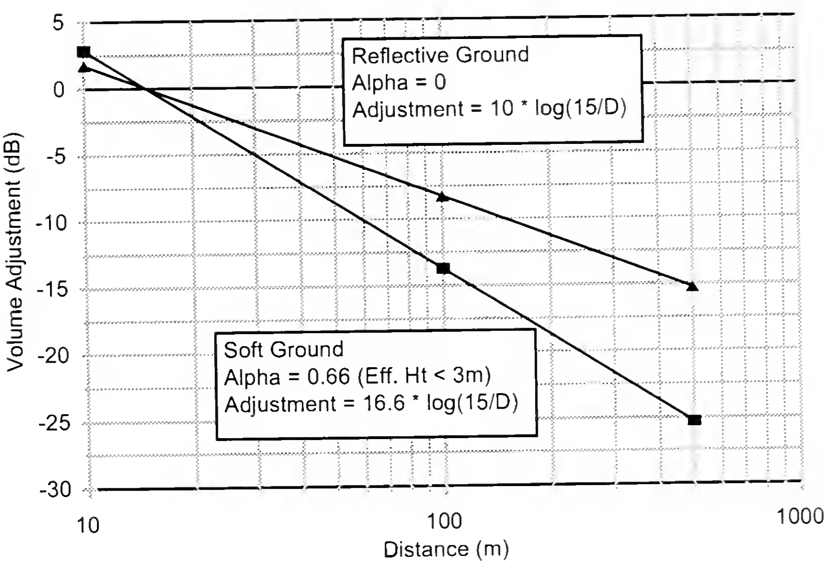


Figure 3: Distance Adjustment

TOTAL EFFECTIVE HEIGHT DEFINITIONS

Topography — **Definition**

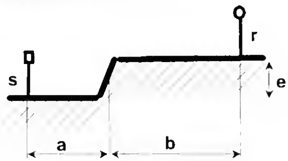
1.

s + r

2.

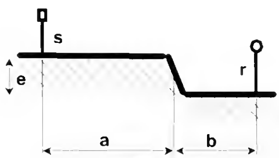
As 1, s + r

3a.



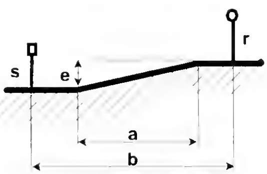
s + r + e, if b < a/2
s + r, else

3b.



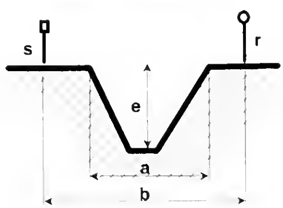
s + r + e, if a < b/2
s + r, else

4.



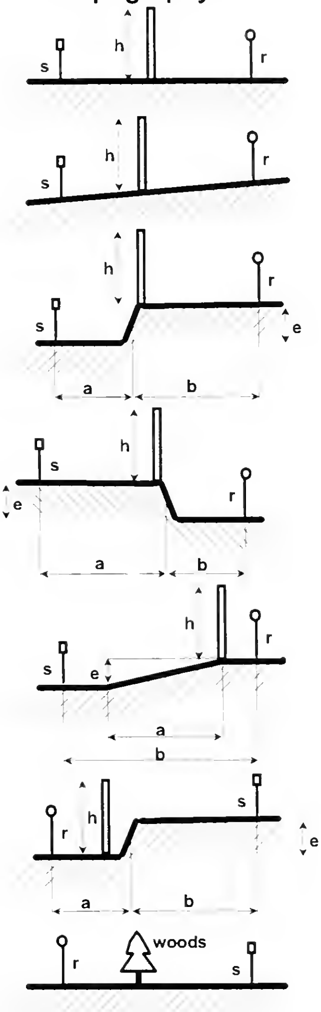
As 2, if a > b/2
As 3, if a < b/2

5.



As 1, if a < b/2
s + r + 2e, if a > b/2

Figure 4: Definitions of the Total Effective Height for Varying Topographies



	Topography	Definition
6.		s + r + 2h
7.		As 6, s + r + 2h
8a.		s + r + e + 2h, if b < a/2 s + r + 2h, else
8b.		s + r + e + 2h, if a < b/2 s + r + 2h, else
9.		As 7, if a > b/2 As 8, if a < b/2
10.		As 3, if h < e s + r + e + 2(h - e), if h > e
11.		s + r + 2w, w = 5 m

Figure 4: Definitions of the Total Effective Height for Varying Topographies (cont.)

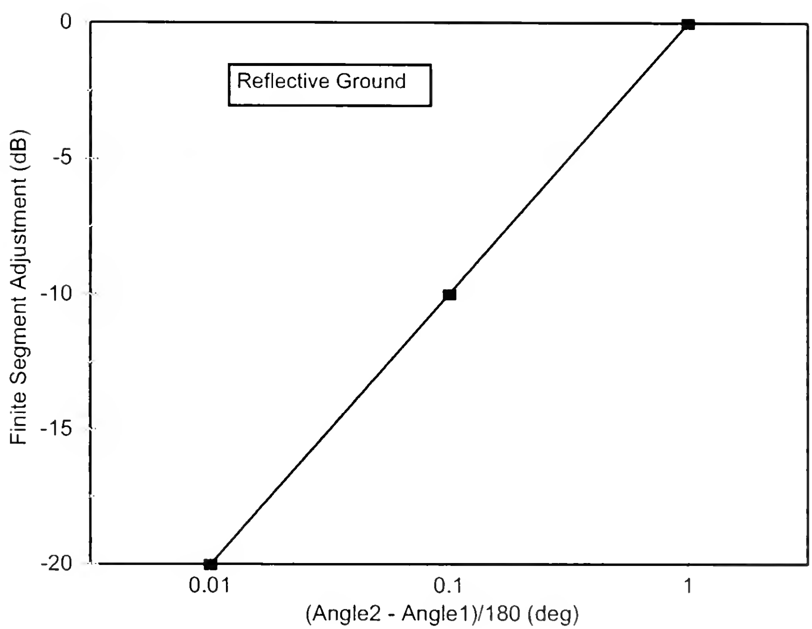


Figure 5: Finite Segment Adjustment (Reflective Ground)

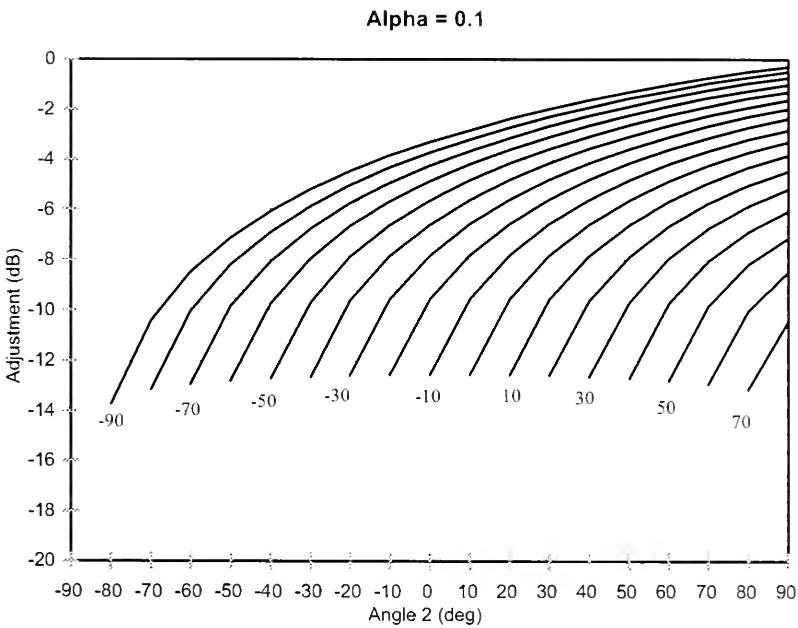


Figure 6.1: Finite Segment Adjustment (Absorptive Ground): Ground Absorption Coefficient, α = 0.1

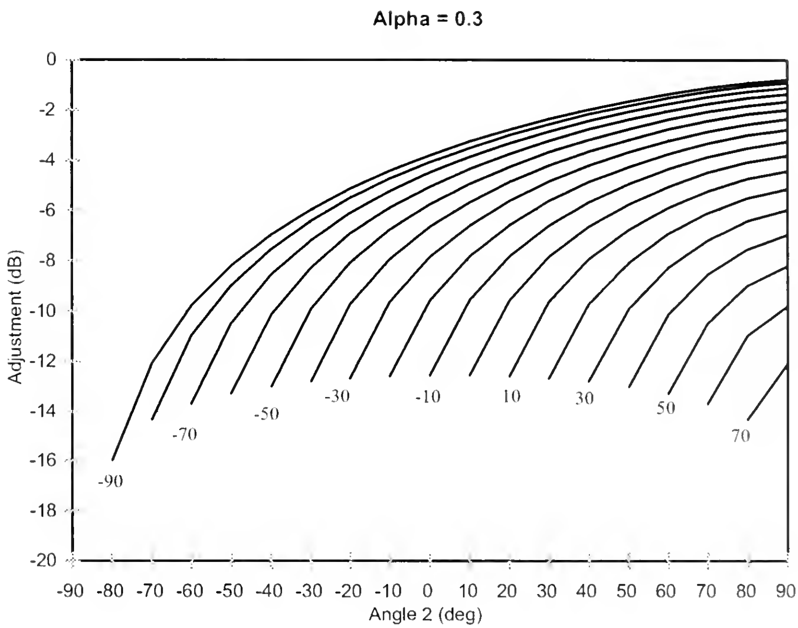


Figure 6.2: Finite Segment Adjustment (Absorptive Ground): Ground Absorption Coefficient, α = 0.3

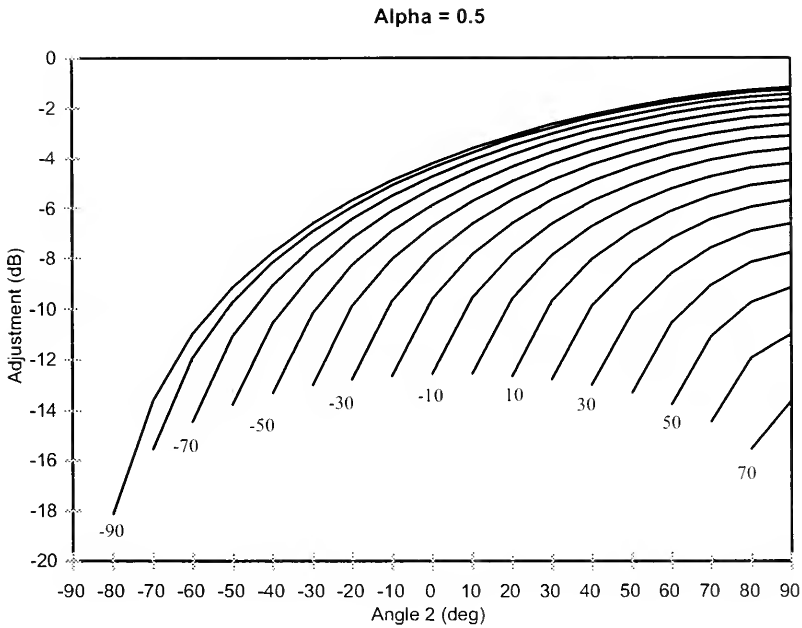


Figure 6.3: Finite Segment Adjustment (Absorptive Ground): Ground Absorption Coefficient, α = 0.5

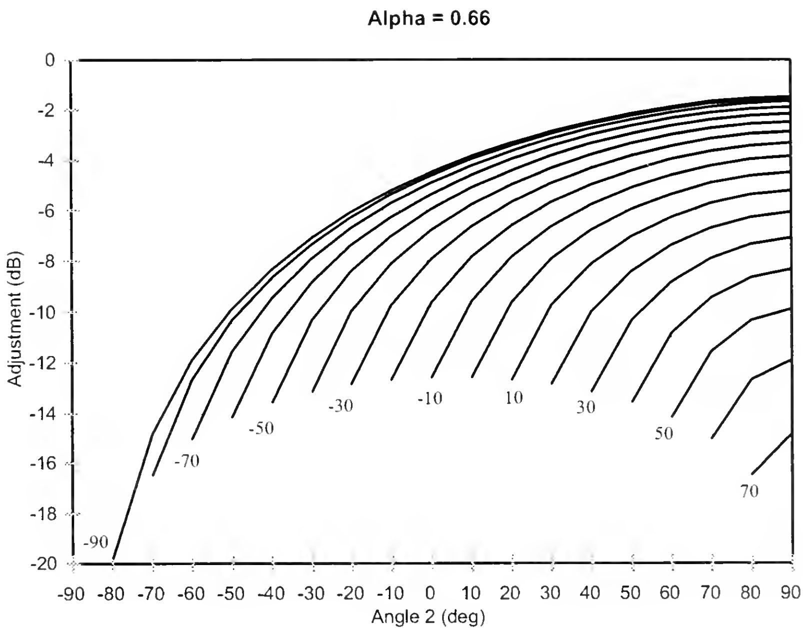


Figure 6.4: Finite Segment Adjustment (Absorptive Ground): Ground Absorption Coefficient, α = 0.66

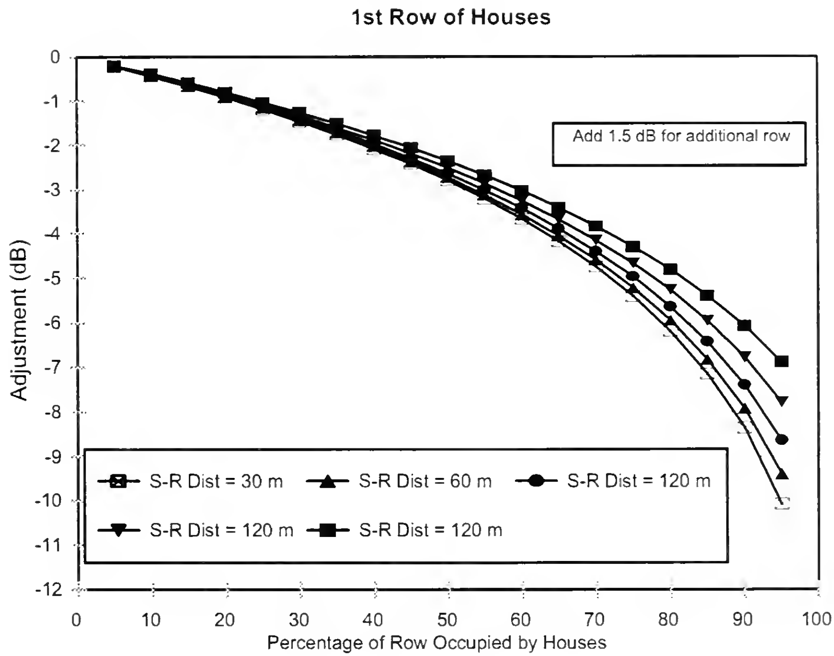


Figure 7: Rows of Houses Adjustment

APPENDIX A

BARRIER ATTENUATION

1. Barriers

A "barrier" is any solid obstacle, natural or man made, which interrupts the line of sight between the observer and the source.

Barriers include such items as elevated/depressed sections of roadway, large buildings, solid rows of town houses, existing topographical features, earth berms and barrier walls. All of these features may reduce the noise level by interfering with the propagation of sound generated by the road traffic.

2. Attenuation Model

A barrier reduces the noise level by interrupting the propagation of sound from the source to the receiver. In optical terms, a barrier creates a "shadow" zone, into which sound can only enter by means of diffraction (bending) over the top of the barrier, and a "bright" zone, where a receiver has an unobstructed view of the source, see Figure A1. The sound level in the shadow zone is reduced (attenuated), while the sound level in the bright zone is largely unaffected by the barrier's presence.

The model used to determine the attenuation of traffic noise by barriers is based on a point source theory of Maekawa [6], as modified by Kurze and Anderson [7] for a line source and barriers of infinite length. The model assumes that the barrier is a thin vertical semi-infinite wall and that sound cannot pass under, around or through the barrier. A cross section of the source-barrier-receiver model is shown in Figure A2.

3. <u>Barrier Attenuation Calculation</u>

The following procedure describes the evaluation method for barrier attenuation of road traffic noise. The procedure is based on the attenuation method presented in the FHWA model [1], but unlike the FHWA method, makes no distinction between walls and earth berms, i.e. applies to barriers of all types.

Step #1 - Determine Path Length Difference

The path length difference (PLD) is the additional distance sound must travel from the source to the receiver, over the top of the barrier.

The vertical cross section is shown in Figure A2. The height 'H_S' is the effective height of the noise source above the roadway. The height 'H_R' is the height of the receiver above the ground. The height of the barrier above the ground is 'H_B'; 'D_{BR}' and 'D_{SB}' are the <u>horizontal</u> distances from the barrier to the receiver and from the barrier to the source, respectively.

The path length difference (PLD), as shown in Figure A2, is the difference between the combined distance from the source to the top of the barrier and then to the receiver, a + b, and the straight line source-to-receiver distance d. It is given by:

$$PLD = a + b - d \qquad \ldots(1)$$

where

$$a = \sqrt{D_{SB}^2 + (H_B - H_S)^2} \qquad \ldots(2)$$

$$b = \sqrt{D_{BR}^2 + (H_B - H_R)^2} \qquad \ldots(3)$$

$$d = \sqrt{(D_{SB} + D_{BR})^2 + (H_S - H_R)^2} \qquad \ldots(4)$$

NOTE:

1. The distances 'D_{SB} ' and 'D_{BR} ' are horizontal distances and, therefore, are not equal to the longitudinal distances when the source-barrier-receiver are not at the same grade.

2. All square roots should be calculated to an accuracy of at least 0.001 metres.

Step #2 - Determine Fresnel Number

The barrier attenuation is dependent not only on the PLD but also on the frequency of the sound generated by road traffic. Both these factors are incorporated into a single descriptor known as the Fresnel Number from which the barrier attenuation is determined.

The Fresnel Number is given by the expression:

$$N_o = \frac{2f}{c} (PLD) \qquad \text{...(5)}$$

where:

f = frequency of the sound (Hertz)
c = speed of sound in air, (= 343 m/sec at 20 deg C)

Although the spectrum of road traffic noise contains frequencies throughout the audible range, numerous studies have shown that the predominant frequency components of road traffic noise are centred at the 500 Hertz band.

Based on an assumption of 500 Hz dominant frequency, equation (5) reduces to:

$$N_o = 2 \frac{500}{343} PLD \qquad \ldots(6)$$

or $N_o = 2.915 \ . \ PLD(m)$ at 20 deg C and at 500 Hz

Step #3 - Calculate Barrier Attenuation

The attenuations (dB) provided by a finite barrier is a function of the Fresnel Number and the subtended angles Θ_1 and Θ_2. The barrier attenuation is given by:

$$A_b = 10 \log \left\{ \frac{1}{\Theta_2 - \Theta_1} \int_{\Theta_1}^{\Theta_2} 10^{-A_p/10} \, d\Theta \right\} \qquad \ldots(7)$$

where:

A_b	is the line source barrier attenuation
A_p	is the point source barrier attenuation
Θ_1, Θ_2	are the angles between the perpendicular line from the receiver to the barrier and the lines from the receiver to left and right-most ends of barrier

and where: ...(8)

$$A_p = \begin{cases} 0 & \text{for } N \le -0.1916 \\ 5 + 20 \log\left\{ \dfrac{\sqrt{2\pi |N_o| \cos\Theta}}{\tan\sqrt{2\pi |N_o| \cos\Theta}} \right\} & \text{for } -0.1916 < N \le 0 \\ 5 & \text{for } N = 0 \\ 5 + 20 \log\left\{ \dfrac{\sqrt{2\pi (N_o) \cos\Theta}}{\tanh\sqrt{2\pi (N_o) \cos\Theta}} \right\} & \text{for } 0 < N \le 5.03 \\ 20 & \text{for } N > 5.03 \end{cases}$$

where $N = N_o \cos\Theta$

Graphical representation of these relationships is shown in Figures A3 and A4.

The barrier in the above described method is assumed to be straight and parallel to the roadway. Where a barrier provides only partial shielding and is not parallel to the roadway, the projected length of the barrier parallel to the roadway must be used in determining the barrier attenuation.

4. Actual Reduction in Noise Level Produced by Barriers

As shown in Figures A3 and A4, barrier attenuation increases with the increase in the Fresnel Number. Both positive and negative Fresnel Numbers may occur depending on source-barrier-receiver geometry. A negative Fresnel Number indicates a PLD less than zero, i.e. a situation in which the path of the sound from the source to the receiver is not intercepted by the barrier but may still be affected by it.

Based on field studies conducted by numerous independent agencies, the maximum attenuation of traffic sound which may be provided by a barrier is about 20 dBA. For artificial barriers such as earth berms and noise barrier walls which have a practical height limit of about 5 to 6 m, barrier attenuation greater than about 10 dB for most source-barrier-receiver geometries are often difficult to achieve.

It should be noted that the barrier attenuation as determined in Section 3 may not, depending on the type of ground cover, be the actual reduction in traffic noise with respect to the free field condition. This reduction is referred to as "barrier insertion loss" and is simply the difference in sound level with and without the barrier in place.

Where the ground surface between the road and the observer is sound reflective, the "barrier attenuation" is equal to the "barrier insertion loss". However, where the ground surface is sound absorptive, depending on the source-barrier-receiver geometry, the barrier insertion loss is lower than the barrier attenuation, due to loss of ground attenuation.

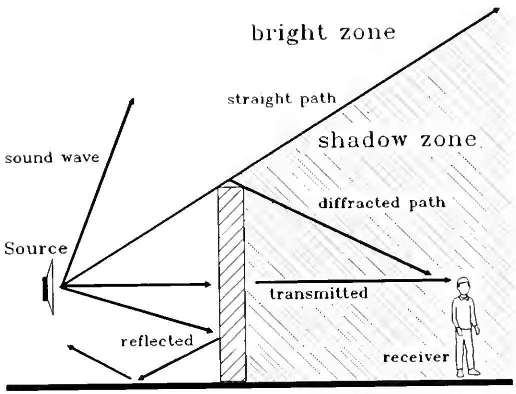


Figure A1: Barrier Cross-section

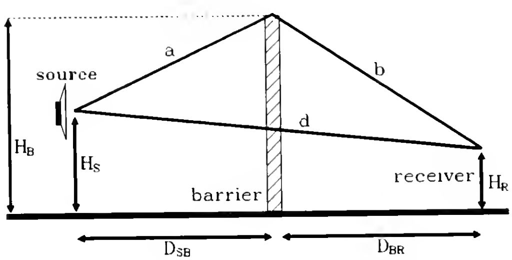


Figure A2: Barrier, Source and Receiver Configuration

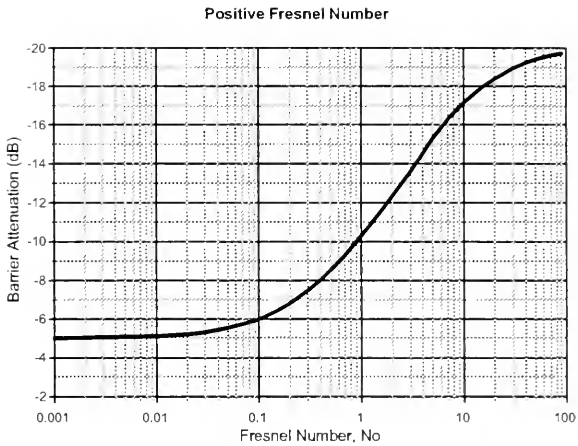


Figure A3: Barrier Attenuation vs. Fresnel Number for Infinite Barriers

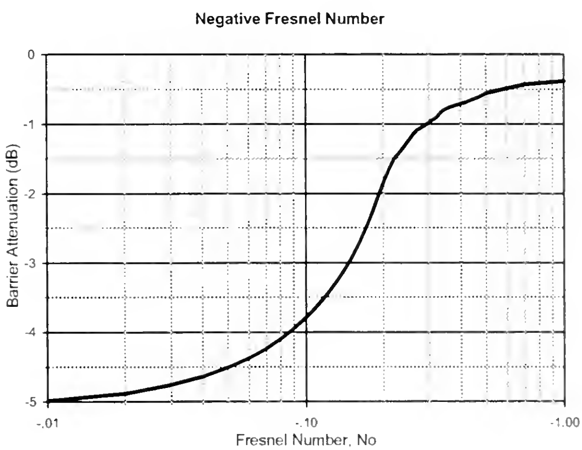


Figure A4: Barrier Attenuation vs. Fresnel Number for Infinite Barriers (Negative Fresnel Numbers)

APPENDIX B

ADJUSTMENT FOR ROWS OF HOUSES

The procedure for evaluating the attenuation provided by a row of houses is based on a model in which the row consisting of the house structures separated by gaps is re-arranged into two zones. The first is defined by a continuous barrier of height equal to the average height of the houses and of length proportional to percentage of the row occupied by the houses. The second is defined by an opening of length proportional to the percentage of the row taken up by the gaps between houses [8,9].

An assumption is then made that the sound propagation can be separated into two parts:

1. Propagation over a continuous row of houses, with no gaps between the structures.

2. Unobstructed propagation over ground.

Other assumptions made in this method are that the effective source height of road traffic is equal to 2 m, receiver height is 1.5 m, average height of a house is 7 m, and the barrier attenuation provided by a solid (uninterrupted) row of houses, if infinite, is 15 dB.

The following steps describe the procedure. The fraction 'p' defines the total amount of gaps (openings) within the row, i.e.

100 p is the % of openings in a row
100 (1-p) is the % of houses in a row

Step #1: <u>Determine adjustment assuming no houses</u>

(a) Effective height,

$h_{eff} = s + r = 2 + 1.5 = 3.5$ m (Figure 4)

Ground Absorption Coefficient,

$\alpha = 0.75\ (1 - h_{eff}/25) = 0.645$ (Section 5.5)

(b) Determine the Distance Adjustment A_d (Section 5.5) and Finite Segment Adjustment A_f (Section 5.6).

(c) Adjustment is given by the Distance and Finite Segments Adjustments:

$$A_1 = A_d + A_f$$

Step #2: <u>Determine adjustment for opening</u>

(a) Effective height,

$h_{eff} = s + r = 2 + 1.5 = 3.5$ m (Figure 4)

Ground Absorption Coefficient,

$\alpha = 0.75\ (1 - h_{eff}/25) = 0.645$ (Section 5.5)

(b) Determine the Distance Adjustment A_d (Section 5.5) and Finite Segment Adjustment A_f (Section 5.6).

(c) Adjustment is given by the Distance and Finite Segments Adjustments, corrected for the percentage of openings:

$$A_2 = A_d + A_f + 10\log(p)$$

Step #3: <u>Determine adjustment for houses forming a barrier</u>

(a) Effective height,

$$h_{eff} = s + r + 2h = 3.5 + 14 = 17.5 \text{ m} \qquad \text{(Figure 4)}$$

Ground Absorption Coefficient,

$$\alpha = 0.75\ (1 - h_{eff}/25) = 0.225 \qquad \text{(Section 5.5)}$$

(b) Determine the Distance Adjustment A_d (Section 5.5) and Finite Segment Adjustment A_f (Section 5.6).

(c) Adjustment is given by the Distance and Finite Segment Adjustments in combination with a barrier attenuation, corrected for the percentage of houses:

$$A_3 = A_d + A_f - 15 + 10 \log(1-p)$$

Step #3: <u>Determine the resultant Adjustment for Row of Houses</u>

$$A_h = 10 \log[\ 10^{A_2/10} + 10^{A_3/10}\ ] - A_1$$

APPENDIX C

WORKSHEET METHOD

A worksheet method to calculate the one-hour equivalent sound level, L_{eq}, uses the tabulated values of the reference sound level and the adjustments contained in Tables 1 to 15. Due to the complexity of some the mathematical expressions defining the tabulated values, the results obtained using this method are not as accurate as a direct evaluation of the expressions by means, for example, of a computer program. Particular caution has to be exercised when this method is used in a situation containing a barrier of finite extent.

Line 1 - Lanes/Road Segment

A concise definition of a road segment is that it is a section of the roadway with the following properties:

(i) the width must not be more than 4 road lanes;

(ii) parameters defining the L_{eq} must be the same within the segment; these include road alignment, road gradient, pavement surface, ground surface and shielding.

Refer to Section 3.2, Subsection 1, Identification of Road Segments, for a full definition of a roadway segment.

Enter the lane designations for each Segment, where appropriate.

Lines 2 to 6 - Traffic Volume

Complete lines 2 to 4 from the given traffic data for the three vehicle categories.

Determine the total volume of the three vehicle categories and enter on line 5.

Enter the given posted speed limit on line 6.

Line 7 Heavy Trucks / Total Volume (%)

Divide line 4 by line 5 and multiply by 100 to get percentage. The volume of heavy trucks is expressed as a percentage of the total volume.

Line 8 to 10 Adjusted Heavy Trucks (Road Gradient)

Enter the road gradient information on line 8.

Using line 8, determine the adjustment factor for heavy trucks on up-hill grades from Table 1 and enter on line 9.

Multiply line 4 by line 9 to determine the adjusted volume and enter on line 10.

Line 11 Total Trucks

Add line 3 and line 10 and enter the total.

Line 12 Medium Trucks / Total Trucks (%)

Divide line 3 by line 11 and multiply by 100 to get percentage. The volume of medium trucks is expressed as a percentage of the total volume of trucks.

Line 13 Total Trucks / Total Volume (%)

Divide line 11 by line 5 and multiply by 100 to get percentage. The total trucks volume is expressed as a percentage of the total traffic volume.

Line 14 Reference Level

Using lines 12 and 13, determine the Reference Sound level from one of the appropriate Tables 3 to 6. Enter this on line 14.

Medium Trucks Range (%)	Table
0 to 25	3
26 to 50	4
51 to 75	5
76 to 100	6

Line 15 to 19 Effective Height

Using line 7, determine the source height from Table 8 and enter on line 15.

Enter the receiver height on line 16.

Refer to Figure 4, enter the elevation change and barrier height, where appropriate, on lines 17 and 18, respectively.

Refer to Figure 4, determine the total effective height and enter on line 19.

Line 20 Volume Adjustment

Using line 5, determine the adjustment for volume from Table 2 and enter on line 20.

Lines 21 to 22 Distance Adjustment

Enter the distance on line 21.

Using line 21, determine the adjustment for distance from Table 7 and enter on line 22.

Lines 23 to 26 Finite Segment Size Adjustment

Refer to Table 10, determine the angles $\varnothing_1$ and $\varnothing_2$, and enter on lines 23 and 24 respectively.

Using line 19, determine the ground absorption coefficient from Table 7 and enter on line 25.

Using lines 23 to 25, determine the adjustment for road segment size from one of the appropriate Tables 9, 11.1, 11.2, 11.3 and 11.4. Enter this on line 26.

Absorption Coefficient	Table
0	9
0.1	11.1
0.3	11.2
0.5	11.3
0.66	11.4

Line 27 Pavement Surface Adjustment

Determine the adjustment for pavement surface type from Table 12 and enter on line 27.

Line 28 Woods Adjustment

Determine the adjustment for woods from Table 13 and enter on line 28.

Line 29 Rows of Houses Adjustment

Determine the adjustment for rows of houses from Table 14 and enter on line 29.

Lines 30 to 34 Barrier Adjustment

Refer to Table C1, determine the barrier angles Θ_1 and Θ_2, and enter on lines 30 and 31 respectively.

Using lines 30 and 31, determine the finite barrier index (FBI) from Table C1 and enter on line 32.

Refer to Table C2, determine the path length difference (PLD) and enter on line 33

Using lines 32 to 33, determine the adjustment for barrier attenuation from Table C2 and enter on line 34.

Line 35 Segment L_{eq}

Add lines 14, 20, 22, 26 to 29 and 34 and enter on line 35.

Line 36 Road L_{eq}

Determine the combined road L_{eq} by logarithmic addition of all segment L_{eq}.

6.1 Example

Problem

Refer to Figure C1. Using the traffic information provided, determine the one-hour equivalent sound levels, L_{eq}, at the receiver location before and after barrier construction.

The road is flat with no gradient, infinitely long and paved with typical asphalt. The road and the surrounding terrain are at the same grade; the ground is non-reflective. The receiver is located 1.5 metres above ground. The barrier is 3 metres high.

Solution

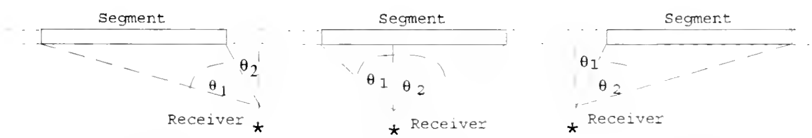
The traffic sound levels before and after barrier construction have been calculated and shown in Figures C2 and C3.

Before the barrier is constructed, only one segment extending from -90 to 90 degrees needs to be defined as the road is infinite and no parameters change within the segment area. Once the barrier is constructed, however, two segments must be used as the barrier presence changes the parameters. The barrier angles Θ_1 and Θ_2 (-90 and 70 deg) define the segment angles ϕ_1 and ϕ_2.

TABLE C1

Finite Barrier Index for Asymmetric Barriers

Leftmost Barrier Angle, θ_1	Rightmost Barrier Angle, θ_2 (degrees)																	
	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
-90	1	2	3	4	6	7	9	9	9	10	12	12	12	12	14	12	12	9
-80	-	5	8	10	10	14	15	15	18	18	19	19	19	19	19	19	18	12
-70	-	-	10	11	15	15	18	19	19	19	19	19	19	19	19	19	19	12
-60	-	-	-	15	18	19	19	19	20	20	20	20	20	20	20	19	19	14
-50	-	-	-	-	19	20	20	20	21	21	23	21	21	21	20	19	19	12
-40	-	-	-	-	-	20	21	23	23	23	23	23	23	21	20	19	19	12
-30	-	-	-	-	-	-	23	23	23	23	23	23	23	23	20	19	19	12
-20	-	-	-	-	-	-	-	23	23	23	23	23	23	23	20	19	18	12
-10	-	-	-	-	-	-	-	-	24	24	23	23	23	21	20	19	18	12
0	-	-	-	-	-	-	-	-	-	24	23	23	23	21	20	19	15	10
10	-	-	-	-	-	-	-	-	-	-	23	23	23	20	19	19	15	9
20	-	-	-	-	-	-	-	-	-	-	-	23	21	20	19	18	14	9
30	-	-	-	-	-	-	-	-	-	-	-	-	20	20	19	15	10	7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	19	18	15	10	6
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	11	10	4
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	8	3
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1



θ_1 is negative
θ_2 is negative

θ_1 is negative
θ_2 is positive

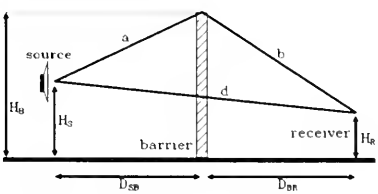
θ_1 is positive
θ_2 is positive

Note: For angles not in the table, use the nearest listed values.

TABLE C2

Barrier Attenuation for Various Values of Finite Barrier Index

Path Length Diff. (m)	Finite Barrier Index																			
	1	2	3	4	5	6	7	8	9	10	11	12	14	15	18	19	20	21	23	24
0.00	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
0.03	-5	-5	-5	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-7
0.10	-5	-6	-6	-6	-6	-7	-7	-7	-7	-7	-7	-7	-7	-8	-8	-8	-8	-8	-9	-9
0.17	-6	-6	-7	-7	-7	-7	-7	-7	-8	-8	-8	-8	-8	-9	-9	-9	-9	-10	-10	-11
0.24	-6	-6	-7	-7	-7	-8	-8	-8	-9	-9	-9	-9	-9	-9	-10	-10	-10	-11	-11	-12
0.28	-6	-7	-8	-8	-8	-9	-9	-9	-9	-9	-9	-10	-10	-10	-10	-11	-11	-12	-12	-12
0.34	-6	-7	-8	-8	-8	-9	-9	-9	-10	-10	-10	-10	-10	-11	-11	-12	-12	-13	-13	-13
0.52	-7	-8	-8	-9	-9	-10	-10	-10	-11	-11	-12	-11	-11	-12	-13	-13	-14	-14	-14	-15
0.69	-7	-8	-9	-10	-10	-10	-11	-11	-12	-12	-13	-12	-12	-13	-14	-14	-15	-15	-16	-16
1.03	-8	-9	-10	-11	-12	-12	-12	-13	-13	-14	-14	-14	-15	-15	-15	-16	-17	-17	-18	-18
1.38	-9	-10	-11	-12	-13	-13	-13	-14	-14	-15	-15	-15	-16	-16	-17	-17	-18	-18	-19	-19
1.70	-9	-11	-12	-13	-14	-14	-14	-15	-15	-16	-16	-16	-17	-17	-18	-18	-19	-19	-20	-20
2.06	-10	-11	-13	-14	-14	-14	-15	-16	-16	-16	-16	-16	-17	-18	-18	-19	-20	-20	-20	-20
2.75	-11	-13	-14	-15	-15	-15	-16	-16	-16	-17	-17	-17	-18	-19	-19	-19	-20	-20	-20	-20
3.44	-11	-13	-14	-15	-16	-16	-16	-16	-16	-18	-18	-18	-18	-19	-19	-20	-20	-20	-20	-20
5.16	-12	-14	-15	-16	-17	-17	-17	-17	-17	-18	-18	-18	-19	-20	-20	-20	-20	-20	-20	-20
6.88	-13	-15	-16	-17	-17	-18	-18	-18	-18	-19	-19	-19	-19	-20	-20	-20	-20	-20	-20	-20



Barrier, Source and Receiver Configuration

$$PLD = a + b - d$$

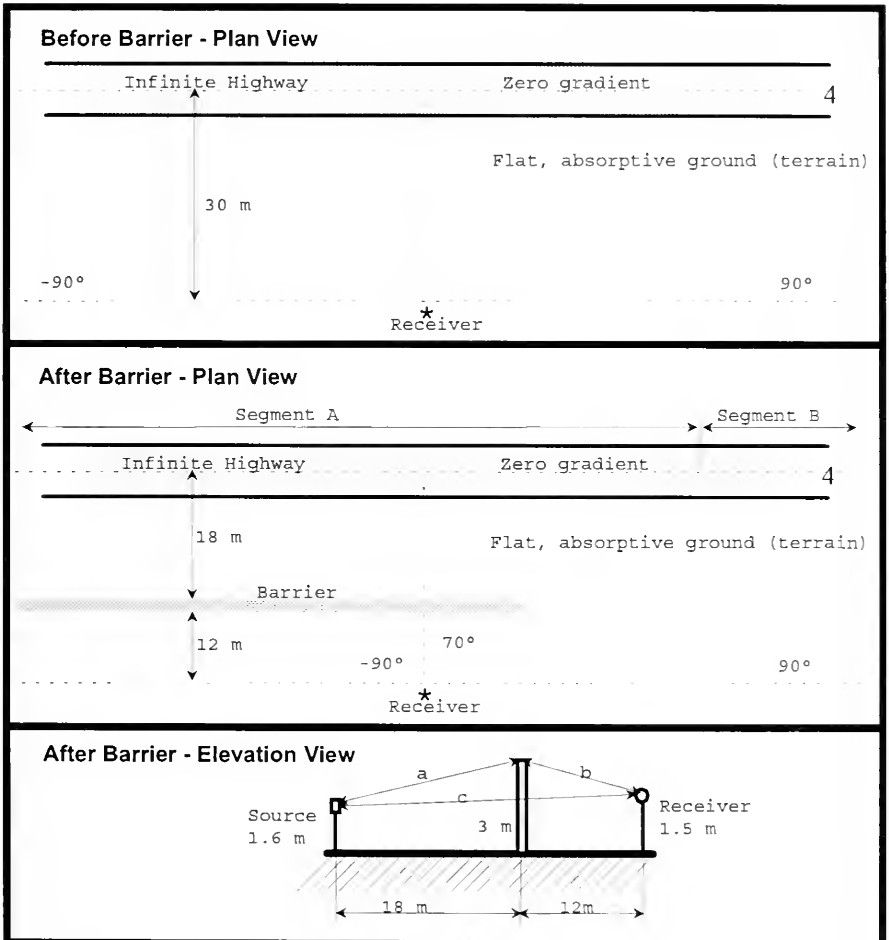
where $a = \sqrt{D_{SB}^2 + (H_B - H_S)^2}$,

$b = \sqrt{D_{BR}^2 + (H_B - H_R)^2}$,

and $d = \sqrt{(D_{SB} + D_{BR})^2 + (H_S - H_R)^2}$

Notes:

1. Obstacle must interrupt the line of sight to be considered as a barrier.
2. Where the calculated PLD is not found in the table, use the nearest listed value.



Traffic Data

Vehicles per Hour			Posted Speed (km/h)
Passanger Cars	Medium Trucks	Heavy Trucks	
910	20	70	80

Figure C1: Example - Conditions on Site

Road Traffic Noise Prediction Worksheet

Name MOE Date 1997 File APP.C Description EXAMPLE

	Time Period		1 hour					
1	Lanes/Road Segments		Before Barr.		After Barr. A		After Barr. B	
2	Number of Automobiles (vph)		910		910		910	
3	Number of Medium Trucks (vph)		20		20		20	
4	Number of Heavy Trucks (vph)		70		70		70	
5	Total Number of Vehicles (vph)		1000		1000		1000	
6	Posted Speed (km/h)		80		80		80	
7	Heavy Trucks/Total Volume(%)	Lines 4 / 5	7		7		7	
	Adjusted Heavy Trucks:							
8	Road Gradient (%)		0		0		0	
9	Adjustment Factor	Table 1	1		1		1	
10	Adjusted Volume (vph)	Lines 4 * 9	70		70		70	
11	Total Trucks (vph)	Lines 3 + 10	90		90		90	
12	Medium Trucks/Total Trucks(%)	Lines 3 / 11	22		22		22	
13	Total Trucks/Total Volume (%)	Lines 11 / 5	9		9		9	
14	Reference Level, L_{eq} (dBA)	Tables 3 - 6		59		59		59
	Heights:							
15	Source Height, s (m)	Table 8	1.6		1.6		1.6	
16	Receiver Height, r (m)		1.5		1.5		1.5	
17	Elevation Change, e (m)	Figure 4						
18	Barrier Height, h (m)	Figure 4			3.0			
19	Total Effective Height (m)	Figure 4	3.1		9.1		3.1	
	Adjustments:							
20	Volume Adjustment (dBA)	Table 2		14		14		14
21	Distance (m)		30		30		30	
22	Distance Adjustment, A_d (dBA)	Table 7		-5		-4.4		-5
23	Angle, ϕ_1 (degrees)	Table 10	-90		-90		70	
24	Angle, ϕ_2 (degrees)	Table 10	90		70		90	
25	Absorption Coefficient, α	Table 7	0.66		0.45		0.66	
26	Finite Segment Adj., A_f (dBA)	Tables 9 & 11		-1.5		-1.4		-14.8
27	Pavement Adjustment, A_p (dBA)	Table 12		0		0		0
28	Woods Adjustment, A_w (dBA)	Table 13		0		0		0
29	Rows of Houses Adj., A_h (dBA)	Table 14		0		0		0
30	Barrier Angle, Θ_1 (degrees)	Table C1			-90			
31	Barrier Angle, Θ_2 (degrees)	Table C1			70			
32	Finite Barrier Index	Table C2			12			
33	Path Length Diff., PLD (m)	Table C2			0.15			
34	Barrier Adjustment, A_b (m)	Table C2		0		-8		
35	Segment L_{eq} (dBA)			66.5		59.2		53.2
36	**Road L_{eq} (dBA)**			66.5	60.2			

APPENDIX D

ROAD TRAFFIC VOLUME CALCULATION

The following information should be obtained when assessing the road traffic noise impact on planned sensitive land uses:

1. The Average Annual Daily Traffic Volume (AADT) and, when available, the Summer Annual Daily Traffic Volume (SADT); the higher of the two should be used;

2. Composition of traffic in terms of the percentages of automobiles, medium trucks and heavy trucks;

3. Posted speed limit (km/h).

When assessing the noise impact, traffic volumes should be based on future traffic projections of at least 10 years after the completion of the planned project or the ultimate capacity indicated by the road authority.

Although the SADT and AADT volumes are 24 hour traffic volumes, the prediction method is based on the 1 hour equivalent sound level, L_{eq}. Furthermore, except for freeways for which the assessment is performed based on the 24 hour traffic volume, the assessment is performed for the 16 hour day-time (07:00 to 23:00) and the 8 hour night-time periods (23:00 to 07:00) separately.

The following expression may be used to convert from the 24 hour road traffic volume information to the 1 hour volume for the 8, 16 or 24 hour periods:

$$\text{Volume (T)} = \frac{\text{24 hour Volume (SADT or AADT)} \times P_T/100}{T}$$

where T is the time period in hours, i.e. 8, 16 or 24 hrs,
and P_T is the percentage of the 24 hour volume in the period T

The recommended day-night traffic volume ratios are:

90% - 10%, for regional roads,
85% - 15%, for provincial roads, and
67% - 33%, i.e. same volume day or night, for freeways.

So, for example, for a regional road for which the day/night traffic volume ratio is 90/10 %, the 1 hour day-time volume is:

$$\text{Volume (1)} = \frac{\text{24 hour Volume (SADT or AADT)} \times 0.9}{16}$$

and the 1 hour night-time volume is:

$$\text{Volume (1)} = \frac{\text{24 hour Volume (SADT or AADT)} \times 0.1}{8}$$

For a freeway, the 1 hour volume (day or night) is:

$$\text{Volume (1)} = \frac{\text{24 hour Volume (SADT or AADT)}}{24}$$

Road Traffic Noise Prediction Worksheet

Name ____________ Date __________ File ____________ Description ______________

	Time Period		1 hour						
1	Lanes/Road Segments			*Before Barr.*		*After Barr. A*		*After Barr. B*	
2	Number of Automobiles	(vph)							
3	Number of Medium Trucks	(vph)							
4	Number of Heavy Trucks	(vph)							
5	Total Number of Vehicles	(vph)							
6	Posted Speed	(km/h)							
7	Heavy Trucks/Total Volume(%)		Lines 4 / 5						
	Adjusted Heavy Trucks:								
8	Road Gradient	(%)							
9	Adjustment Factor		Table 1						
10	Adjusted Volume	(vph)	Lines 4 * 9						
11	Total Trucks	(vph)	Lines 3 + 10						
12	Medium Trucks/Total Trucks(%)		Lines 3 / 11						
13	Total Trucks/Total Volume (%)		Lines 11 / 5						
14	Reference Level, L_{eq} (dBA)		Tables 3 - 6						
	Heights:								
15	Source Height, s	(m)	Table 8						
16	Receiver Height, r	(m)							
17	Elevation Change, e (m)		Figure 4						
18	Barrier Height, h	(m)	Figure 4						
19	Total Effective Height (m)		Figure 4						
	Adjustments:								
20	Volume Adjustment	(dBA)	Table 2						
21	Distance	(m)							
22	Distance Adjustment, A_d	(dBA)	Table 7						
23	Angle, ϕ_1	(degrees)	Table 10						
24	Angle, ϕ_2	(degrees)	Table 10						
25	Absorption Coefficient, α		Table 7						
26	Finite Segment Adj., A_r	(dBA)	Tables 9 & 11						
27	Pavement Adjustment, A_p	(dBA)	Table 12						
28	Woods Adjustment, A_w	(dBA)	Table 13						
29	Rows of Houses Adj., A_h	(dBA)	Table 14						
30	Barrier Angle, Θ_1	(degrees)	Table C1						
31	Barrier Angle, Θ_2	(degrees)	Table C1						
32	Finite Barrier Index		Table C2						
33	Path Length Diff., PLD	(m)	Table C2						
34	Barrier Adjustment, A_b	(m)	Table C2						
35	Segment L_{eq}	(dBA)							
36	**Road L_{eq}**	**(dBA)**							

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